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METEOROLOGICAL AND HYDROLOGICAL SERVICES

Special Sahelian Office

74-00368

1. The problem

The climate of the six Sahelian countries of West Africa, lying approximately between latitudes 10 and 20° N, is semi-arid generally and subject to catastrophic droughts sometimes covering a few successive years. The zone is marginal for production of food and water for an increasing population, estimated at 25 million in 1972, of which nearly 90% are engaged in agriculture. With low rainfall during a short season and high potential evapotranspiration, the ecological system is very fragile. During drought years the imbalance between nature's provisions and the increasing demands of man and his animals results in southwards encroachment of the desert which is difficult to arrest and may be impossible to reverse.

Of the total area of 5.3 million square kilometres, only 27% receive an average annual rainfall in excess of the 500 mm which must be regarded as the lower limit to support a permanent system of rainfed agriculture in that region. About 20 per cent of the total area is too marginal for rain-fed crop cultivation but is partly suitable for migratory livestock herding. Over 50% of the region is desert.

There are proposals to triple the small areas already under irrigated or flood-retreat cultivation in the large river basins but these would still amount to only a small fraction of the total land surface. Moreover production from irrigated areas, although less closely correlated with distribution of rainfall than that from rain-fed crops, will remain dependent upon the vagaries of weather over the river catchment areas further south.

The whole of the Sahelian zone has two very distinct seasons associated with the annual migration of the Intertropical Convergence Zone (ITCZ). The longer season, from September to April, when the ITCZ is to the south, is almost completely dry with nearly cloudless skies and the north-easterly Harmattan from desert regions causing high potential evapotranspiration of about 1600 mm during this season.

During the normal rain season from May to August the moisture-bearing south-westerly winds from the South Atlantic Ocean and the Congo Basin push the ITCZ over the Sahelian zone to its more northerly positions near the Tropic of Cancer in late July and early August. The instability just to the south of the ITCZ gives the rains on which the economy of the zone almost entirely depends.

The timing, intensity and duration of the ITCZ over any part of the zone determine the quality, quantity and length of the rains and the success of the crop cycles. The isolines of mean annual rainfall totals of the region, as shown on figure I at the end of this review, therefore lie almost along lines of latitude, as does the ITCZ, and show a steep rainfall gradient from north to south.

At the frontier of the Saharan desert, the northern parts of the Sahel receive 100 to 400 mm of rain in an average year. This area has for many centuries supported migratory herding of camels, sheep, goats and cattle on sparse xerophytic shrubs and grasses with very few trees, mainly palms and acacias. The Sudanian zone, only a few hundred kilometres nearer the equator, has average annual rainfall of 800 to 1,000 mm and supports sedentary farming of millet, sorghum maize, peas and pulses, groundnuts and cotton.

The well known irregularities in the movements and intensities of the ITCZ from year to year result not only in high variability of total amounts of rainfall but also in the length of the season of crop growth. The isolines of rainfall in 1973, expressed on the lower half of figure I as percentages of the long-period means, indicate that 1973 was again a very dry year over the zone as a whole. The approximate latitudinal alignment of these isolines of percentage in 1973 and the gradient from north to south again reflect the influence of the ITCZ and demonstrate that in drought years it is the northern zones which suffer greater departures from average weather.

Figure II shows the seasonal distribution of rainfall amounts in each 10-day period over 30 years for two stations in Mali - Mopti on the edge of the Sahelian zone (annual total 530 mm) and Bamako in the southern Sudanian zone (1068 mm). The diagrams of values exceeded in 20% and in 80% of all years emphasize the high variability over the years of both rainfall amounts and of length of rain seasons at both stations but especially in the Sahelian zone.

Such climatic conditions result in numerous problems in selection of varieties and species of crops, in adaptation of all husbandry practices and in management generally. Similarly the problems in hydrology and water management, such as those in the supply of water for crop irrigation and for migratory herds as well as for development of transport on rivers and lakes, are a reflection of the shortage and irregularity of rainfall.

Solar energy, which is abundant, and wind energy could apparently be harnessed throughout the Sahelian zone. These sources are virtually unused whilst mineral oil products have to be imported and distributed at great cost and trees are destroyed to supply domestic firewood with the resultant degradation of the environment.

2. Significance of the meteorological and hydrological services sector to the economy and its relationship to other economic sectors

Shortage and irregularity of rain being at the root of problems of the six Sahelian countries, successful development in other sectors must depend upon information from the meteorological and hydrological services sectors.

One of the first problems which comes to mind is the potential in artificial augmentation of rainfall, for any increase in rainfall which could be obtained in this way would clearly be beneficial. Some attempts have already been made to promote increases by cloud seeding but the ways in which operations were carried out make it extremely difficult to assess the results.

There is at present only a remote possibility that weather can be modified to prevent drought. The contribution that meteorological and hydrological services can make towards mitigation of the effects of drought and towards economic development are, however, large. There are two main aspects of the dependence of other sectors on meteorological and hydrological

knowledge. On the one hand pre-investment studies for all development plans require a knowledge of climatic and hydrological factors more complete and in greater detail than is at present available. On the other hand, efficient management in almost all sectors requires forecasting, both climatological forecasting for the longer-term and synoptic weather forecasting in the short-term, which is not available generally to sectors other than aviation. Hydrological forecasting, already initiated within a UNDP/WMO Project in Mali and Guinea will prove of considerable importance for management of water resources.

Without measurement and understanding of weather factors, attempts to develop production, by extension or intensification in normal as well as in dry years, and at the same time to preserve the fragile ecological system of the environment, can only be on a trial and error basis. Such a basis can be costly, time-consuming and possibly disastrous.

It could not be over emphasized that all investment projects dealing with water resources (be it in agriculture, industry, hydropower and water supply) cannot be rationally and economically planned and executed without meteorological and hydrological data resulting from time-series, requiring at least several years of continuous observation in a rationally designed network of meterological and hydrological stations.

Studies of weather/crop correlations are urgently required to improve the early warning of crop failure which is essential for effective preparation of relief of food shortages for men and animals. Also within the agricultural sector, such problems as land utilization, introduction of new varieties and species, modification of husbandry practices and new methods of pasture management all require detailed maps of climatic conditions. These maps should define probabilities of rainfall amounts and timing, vapotranspiration, wind, temperature and radiation for specific areas.

Management of water resources and development of water supplies require similar maps, run-off, river flow and lake level information and estimation of ground water recharge. Hydrological studies involving the close relationship between certain meteorological and hydrological data such as rainfall and runoff and also other relevant hydrological characteristics are necessary for the further planning of investment projects and the optimum use of surface water resources.

Since distribution of disease vectors and pests is largely a function of climatic factors an improvement of knowledge in this sector is necessary in consideration of human, animal and plant health.

Many parts of the industrial, transport and trade sectors will also depend upon climatological and hydrological considerations, especially at the feasibility study stage. Studies on the supply of energy must include examination of the potential uses of solar and wind energy.

The above remarks indicate the urgent necessity for meteorological investigations of past data in pre-investment studies for other sectors. Also forecasts of weather conditions and water supplies will be necessary for efficient operation of most installations and agricultural enterprises.

Short term forecasts are required for many purposes in agriculture. For example preparation of seed beds and sowing of seeds should be determined by forecasts of rain. At present seeds are sown repeatedly, and often uselessly, as from a chosen calendar date until sufficient rain falls to permit successful germination and growth. Use of herbicides and pesticides is successful only if application is followed by favourable weather conditions.

Longer term weather forecasts are required for planning of agricultural operations and pasture control, for forecasting river and lake levels which determine operations in flood-irrigated areas and transportation by water.

3. Achievements in the past

The achievements in the meteorological sector may be considered from three aspects - the climatological data, investigations and forecasting. Development of meteorology in the Sahelian zone has, from all three aspects, been mainly towards the provision of services for aviation and for the regional aspects of the Global Observing System and the Global Telecommunication System of the World Weather Watch.

A network of stations making vertical soundings of the atmosphere has been established and with few additions would be sufficient for upper air meteorology. Data available have been summarized and published. Stations for direct reception of photographs from meteorological satellites have been established in recent years in capitals of three of the six countries but are required also in the other three. The satellite data for the region which have been accumulated over recent years are summarized in NOAA publications.

Climatological data for the 64 synoptic stations in the six countries have been published in summary form over a sufficient number of years to provide 10- and 20-year monthly means of the elements observed for synoptic purposes. The density of this network, averaging one station per 100,000 square kilometres approximately, is however too sparse to provide climatological maps for application to the economy generally.

Relatively few agro-meteorological, climatological and rainfall stations have been established. Detailed observations are stored in the original form in the archives of national services and intergovernmental agencies. Simple summaries have been published in various documents on an increasing scale during recent years. The most centralized sources of published data other than rainfall are the monthly publication of Asecna covering the years 1953 to 1972 and the year books of other agencies. Special mention must be made of the valuable co-operation between Governments, CIEH, ORSTOM and Asecna[1] in collections of daily rainfall data available in the zone and their transfer to punched cards. Publication of these data up to 1965 is expected to be completed for the six Sahelian countries by 1974 and is expected to continue in subsequent years. Publication of data at the national level is developing steadily.

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1) CIEH - Comité Interafricain d'Etudes Hydrauliques, ORSTOM - Office de la Recherches Scientifique et Technique Outre Mer and ASECNA - Agence pour la Securité de la Navigation Aèrienne en Afrique et à Madagascar.

Some hydrological data are also being published at the national level by national services and CIEH and ORSTOM are covering the zone as a whole. Other hydrological publications are available and include ORSTOM mongraphs on the Senegal, Niger, Chari and Lagone rivers and the Unesco monograph on Lake Chad. Three international river commissions have been formed over the last ten years for the development of three large river basins in the region namely the Senegal, the Niger and the Lagone. The work performed by these commissions, though limited and study-oriented, permitted the collection and exchange of useful data and information among the countries concerned.

A few investigations into synoptic meteorology, agro-meteorology, hydro-meteorology and climatology have been made on the basis of the rather sparse data of past years by various agencies. Most of these have been carried out for individual stations and there is a lack of meteorological information on the zone as a whole. Mention may, however, be made of the agro-climatology survey carried out by the FAO/Unesco/WMO Interagency Group in 1963-1967 of which results were published in full in a Technical Report by FAO and in a shortened version as Technical Note No. 86 by WMO[2]. Another valuable contribution to the knowledge of the region as a whole is the series of monthly maps of potential evapotranspiration established by CIEH and published in 1972.

Increased effort has been made during the recent drought years by national services and other agencies to meet the needs for rapid collection and publication of rainfall data in the form of tables, histograms and simple national or regional maps which are necessary for drought monitoring in many sectors of the economy.

Short-term forecasting is carried out in the Regional Meteorological Centre at Dakar and in the six national Meteorological Centres for aviation according to the standards set by WMO and ICAO regulations. The provision of daily forecasts for other sectors of the economy and for the public is limited and variable over the six countries. There is however a new awareness of the need to improve short-term forecasts for special purposes, especially for agriculture.

Attempts have been made by several agencies to analyse the past rainfall data with a view to obtaining indications for forecasting over longer periods, from a week ahead to years ahead but there has been little convincing success in determining any long-term trends or cycles in rainfall amounts over past years.

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2) This survey was followed up by a Technical Conference (Dakar 1971), the proceedings of which were published in WMO Publication No. 340.

4. Objectives and targets for the future

The aims in the meteorological and hydrological services programme for the six Sahelian countries may be divided into three groups. Firstly, investigations on the basis of existing data are urgently required for pre-investment studies in almost all sectors of the economy. Secondly, in the longer-term, it is necessary to restructure the meteorological services Networks of stations to provide observations for all purposes should be established. Local personnel should be trained for processing these observations and interpreting them into summaries, analyses and forecasts for application in all sectors during future years. Thirdly, the study of potentialities in the artificial augmentation of rainfall merits serious consideration.

As regards the investigations using existing data, four problem areas have been identified. The first of these is the urgent necessity to establish weather/crop correlations to improve the early warning system of crop failure. This early warning system is designed to assist provision of food and establishment of other emergency plans to mitigate the catastrophic effects of drought years. A useful monitoring of rainfall has been carried out by the World Food Programme and other agencies through 1973 but the aim must be to interpret weather data into an assessment of future food production. This can only be done if weather/crop correlations are established. The studies in this field should be carried out during the first half of 1974 and extended over a period of testing during the rain season May to August 1974.

The other three fields of investigation are designed essentially to provide meteorological and hydrological analyses for the many pre-investment studies which will be necessary in other sectors of the economy during the next year or two. They will however also be of permanent value in all later development projects as well as in the operational activities in all sectors.

Details of these three fields of investigations are given in the following section listing and describing all projects. On the one hand they consist of meteorological and hydrological studies involving the establishment of weather/water runoff correlations, surface water mapping and maps of agricultural and water resources potential. These preinvestment studies are a prerequisite for the development and regulation of the many drainage systems which cover a substantial portion of the area of the region and which include many major rivers : the Senegal, the Niger, the Volta, the Lagone, the Komadougou and the Chari rivers. Such studies are also necessary for the formulation of short and long-term prevention measures which should be taken to alleviate the effects of droughts and for the resolution of some important policy issues regarding the use of the international rivers in the region.

On the other hand they will include two separate approaches to longer period forecasting through statistical studies of past data and through investigations into cause and effect of the changing pattern of the global circulation of the atmosphere.

The next group of objectives are for the longer term assistance of meteorological and hydrological services to promotion of economic growth in general and to mitigation of the effects of drought. In periods of favourable as well as unfavourable weather it is generally agreed, since the success or failure of man's activities are determined by nature's provisions, that meteorological knowledge is necessary to promote man's well-being. In the six Sahelian countries it is particularly necessary that meteorological knowledge should be raised to the standards achieved in most parts of the world. The objectives must be to restructure and expand meteorological and hydrological services so that they may in future provide the necessary assistance to all sectors of the economy. Particular emphasis must be placed on application of meteorology to agricultural production for increasing populations and to protection of the environment in drought periods when weather tips the delicate balance against vegetation and towards further encroachment of the desert.

This objective requires the establishment of well-planned networks of stations for agro-meteorology, hydro-meteorology, climatology and hydrology, as well as for aeronautical meteorology. These networks must provide observations over the territories as a whole wherever man may live as well as in the better-watered Sudanian zone where activity has been concentrated in the past.

The interpretation of these observations for application in all economic sectors requires an adequate establishment of fully-trained African meteorologists and hydrologists and buildings and equipment for centralized meteorological and hydrological services. In the interests of economy and efficiency these services should be established at two levels - the national and regional levels.

Finally, the potentialities in the artificial augmentation of rainfall must be examined. The first objective must be conclusions on the possibilities of increasing rainfall, especially in dry years and identification of problems which may arise in practice. Also, in view of the high cost of operations, a cost/benefit analysis must be attempted. The design of such studies is being examined but no specific proposals are made at this stage.

5. Potential projects

Projects to meet the objectives in pre-investment studies on existing data and in the restructuring of national meteorological and related hydrological services are listed below. The investment figures indicated are not based on detailed surveys in all cases and give an order of magnitude until further study permits elaboration of the proposals.

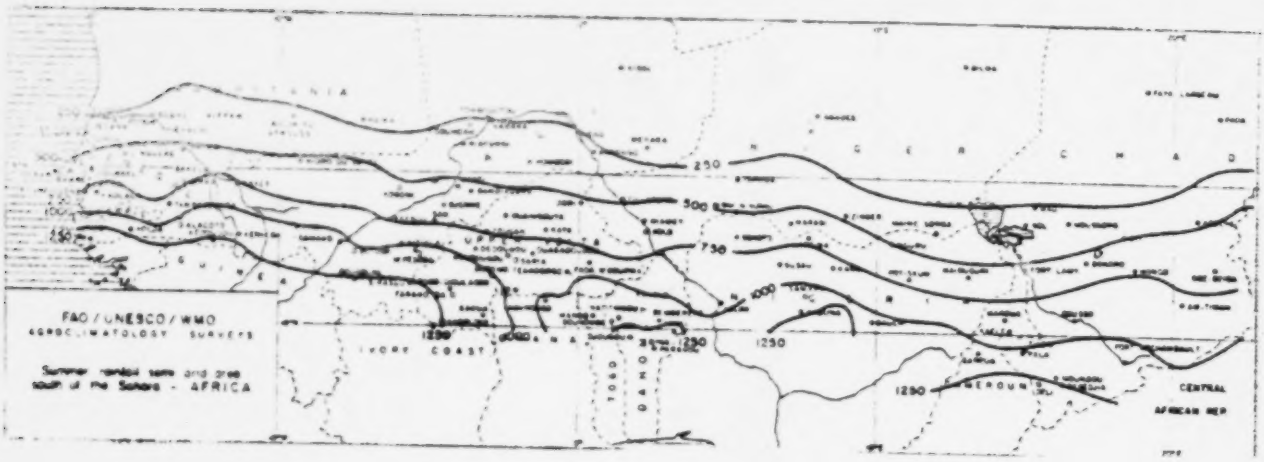
Further detail and breakdown of the costs of the projects are given in Appendices A and B.

Project I - Studies	Investment U.S. $ 1,000
Establishment of crop/weather correlations to improve the early warning system	50
Establishment of weather/run-off correlations and maps of agricultural and water resources potential	70
Further studies of possible trends and persistence and periodic recurrence of characteristics in monthly and annual rainfall	10
Studies of droughts in tropical and sub-tropical belts with particular reference to the Sudano-Sahelian zone and the general atmospheric circulation	30
	160
Project II - Restructuring of Meteorological and Hydrological Services	
Improvement and expansion of national services	
Creation of Sudano-Sahelian Hydrometeorological Centre and Regional Training School	
	6,700

FIGURE I

Rainfall of the Sudano-Sahelian zone of West Africa

Mean annual isohyets



Isolin s of 1973 rainfall expressed as a percentage of the means

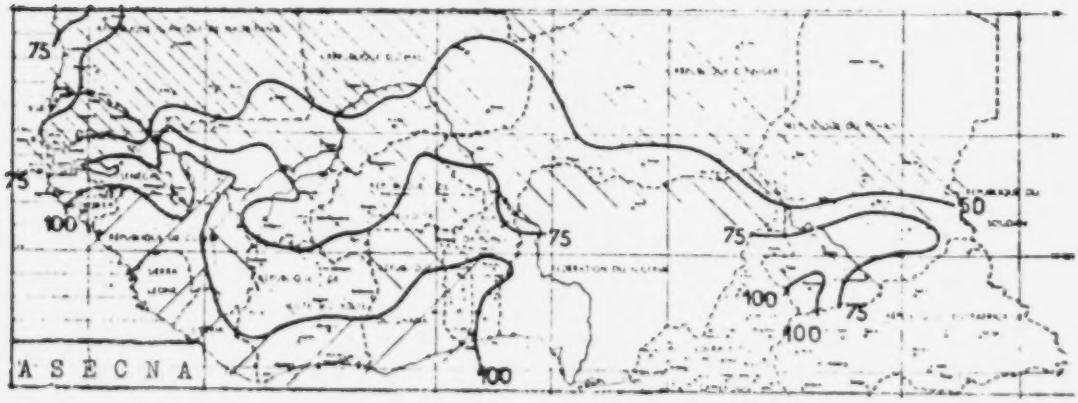
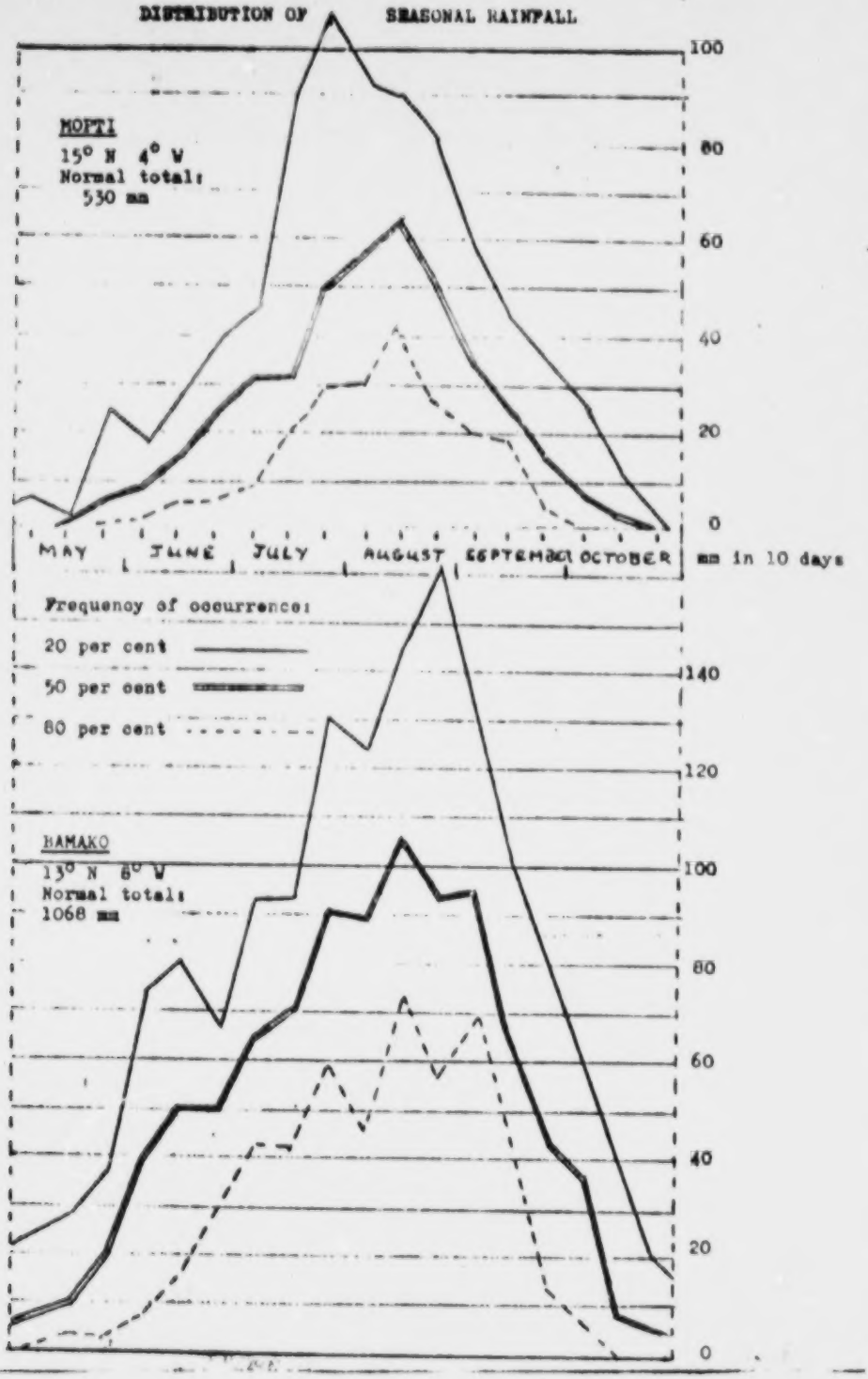


FIGURE II

DISTRIBUTION OF SEASONAL RAINFALL



Project I - Studies

1. Establishment of crop/weather correlations

Objective

Improvement of early warning system for crop failure and of general planning of food supplies and commercial crops during each year. Completion by August 1974.

External input — U.S. $ 1,000

Expert services - two for 6 months
- one agrometeorologist, one agronomist

12 man months	30
Travel and miscellaneous	20
	50

Description

Collections of data on some weather elements and production of some crops in past years have already been made. Additional information is available in the Sudano-Sahelian countries and research agencies. Correlations of these crop/weather data, such as have successfully been made in other countries, would help to improve planning for 1974/75 and future years.

2. Establishment of weather/run-off correlations and compilation of maps of agricultural and water resources potentials

Objective

Provision of pre-investment knowledge for projects in development of water resources and agriculture.

External input

Expert services - three for six months
- one agrometeorologist, one agronomist and one hydrologist

	U.S. $ 1,000
18 man months	45
Travel, publications and miscellaneous	25
	70

Description

The balance between natural factors and between man and nature in the fragile eco-system of the Sudano-Sahelian countries is very delicate. Projects for development of water resources, agriculture and protection of the soil and its vegetation cover can only be well founded at the outset if they are based on knowledge of meteorological and hydrological factors.

In definition of policies for development and management of forestry and fishing and of sedentary agriculture and nomadic herding, the most frequent problems are selection of areas, of species and varieties and of husbandry methods. These selections necessarily depend upon weather factors. Similarly development and management of water resources must be determined after assessments of river flows and recharge of surface and underground water reservoirs which also largely depend upon rainfall and evapotranspiration.

The time factor involved in successful assessment of water run-off or of appropriate periods at which to sow seeds may be no more than 24 hours. Pasture production and germination and flower fertilization in cultivated crops are determined by weather over periods no longer than five to ten days. In the Sudano-Sahelian zone a healthy, well established, plantation of sorghum, millet or maize may produce almost nothing at harvest if a dry period of ten to fifteen days arrests plant growth or grain development.

Different varieties of crops have different lengths of cycle from germination to maturity so that successful production depends upon the length of the period of useful rains which is highly variable over the zone both in space and in time. It is not infrequent in the Sudano-Sahelian zone that seeds are repeatedly sown, as many as four or more times, before soil moisture is adequate for establishment of young plants. Sowing so late in the season that there is no reasonable hope of completion of the crop cycle beforedesiccating weather sets in is also reported.

Most of the climatological studies already made, including the FAO/Unesco/WMO Agrometeorological Survey made over the zone in 1963-67, have been mainly on data averaged over periods of a month and simple monthly averages have been derived over periods of years. Such investigations as have been made into the effects of weather over short periods on crop production have been applicable to particular varieties at isolated stations, mainly near the large river basins, and insufficiently comprehensive.

Development of agricultural production and water resources over the Sudano-Sahelian zone as a whole requires analysis of weather factors over short periods and the compilations of maps showing, for each identifiable area and for each of the more important crops, the beginning and end of the season of weather suitable for the crop cycle and regularity of the weather during the season.

In defining areas suitable for different crops a failure rate of 20% of all years is considered acceptable. The apparent complexity of the task of preparing maps will necessarily be reduced by concentration on rainfall data in the absence in many areas of comprehensive observations of evapotranspiration or wind, radiation and air temperatures and humidity.

These studies are closely connected with that of crop/weather correlations and are separated therefrom only because of the extreme urgency of improving the early warning system before possible crop failure during the next rain season.

It is recommended that the whole of these studies should be regarded as a follow-up of the Agroclimatological Survey of a Semi-arid Area in Africa South of the Sahara which was carried out in 1963-1967 as an FAO/Unesco/WMO Interagency project. Results of this survey were published in full in a Technical Report by FAO and in a shortened version as Technical Note No. 86 by WMO.

3. Further studies of trends and of persistence and periodic recurrence of characteristics of monthly and annual rainfall

Objective

Determination of probabilities of characteristics of future rain seasons with particular reference to:

(i) total amount of rainfall;

(ii) beginning, end and length of season of useful rains.

External input — U.S. $ 1,000

Expert services - one statistical climatologist

4 man months — 10

Description

Efficient planning in every sector of the socio-economic structure would be aided by a knowledge of statistical probability of future climatic factors in the long-term, in the years immediately ahead or in the remainder of a rain season.

Various investigators have searched for trends and cycles of rainfall. Convincing evidence has not yet been found either of long-term trends or cycles sufficient to give guidance for the future. But previous studies have mostly been on total annual rainfall data from individual stations which may not have been statistically representative of large areas. The fundamental importance of even approximate forecasts for future years, seasons or parts of seasons justifies further statistical investigations based on monthly and annual rainfall averaged over latitudinal sub-zones and on river flows and lake levels.

4. Studies of droughts in tropical and sub-tropical belts with particular reference to the Sudano-Sahelian zone and the general atmospheric circulation

Objective

Provision of long-term forecasts derived from correlations of weather fluctuations in the Sudano-Sahelian zone with preceding weather factors over other areas of the globe.

External input	U.S. $ 1,000
Expert services - two for six months - one synoptic meteorologist - one dynamic climatologist	
12 man months	25
Miscellaneous	5
	30

Description

Indications of future climatic factors a season or even only ten days ahead would greatly aid planning in agriculture and water resources over the shorter term.

Certainly the amount of rainfall and the length of the rain season in the Sudano-Sahelian zone are functions of the intensity and movements of the Inter-tropical Convergence Zone (ITCZ) in the northern part of its annual migration during the period from May to September. The intensity and movements of the ITCZ are mainly dependent upon those of the semi-permanent anticyclones centred in the regions of the Azores, St. Helena and Libya. Studies of the changing characteristics of these anticyclones in relation to rainfall in the Sudano-Sahelian sub-zones might show up correlations which would have value for prognosis of rainfall a few days or for longer periods ahead.

Nevertheless there is much evidence that the phenomenon of seasonal and monthly rainfall deficits over large belts is global and not peculiar to the semi-arid area to the south of the Sahara. In 1972 the drought extended in a belt between latitudes 10° and 20°N from America through Africa to Asia; many other areas in southern Africa and other parts of the world also had relatively large rainfall deficits.

The causes of large-scale drought may be expressed in terms of abnormalities in the general circulation of the atmosphere and in the intensity and position of the major belts of high and low atmospheric pressure. But there is poor understanding of the causes of these abnormalities, which have been attributed to sunspots, volcanic dust or other pollution of the atmosphere and, more recently, to oil pollution of the ocean surfaces. Whatever may be the causes, there is much potential value in searches for correlation between rainfall and the abnormalities of the general circulation for some of these correlations could have value in longer-period forecasting.

Several studies have already been made in this field but it is recommended that special effort now be made to correlate the large variations of seasonal rainfall in many tropical and sub-tropical belts of the world with abnormalities of the atmospheric circulation systems. The Sudano-Sahelian zone now deserves a special attention in such studies which could eventually be extended to other areas subject to large-scale drought.

Project II - Development of Meteorological and Hydrological Services in the Sudano-Sahelian zone

Objectives

Development of meteorological organization capable of providing service to all sectors of the economy in the Sudano-Sahelian zone as a whole and in individual countries.

This project consists of two inter-dependent parts:

A. Improvement and expansion of National Meteorological and Hydrological Services in each of the six Sudano-Sahelian countries providing:

(i) adequate data from planned networks of stations making routine observations for all meteorological and hydrological purposes;

(ii) collection and verification of all data and storage in national archives;

(iii) interpretations of data at the national level;

(iv) expert advice to other sectors of the national economy; and

(v) close co-operation with the Sudano-Sahelian Meteorological Centre.

B. Creation of a Sudano-Sahelian Meteorological Centre and Regional Training School providing:

(i) centralized services in stores supplies and instrument repairs and calibration;

(ii) centralized services in climatological data processing, summarization and publication;

(iii) sub-regional map compilation, research and investigations;

(iv) sub-regional longer-period forecasts; and

(v) training facilities for Classes II and III meteorologists and hydrologists.

External input	U.S. $ 1,000
National Meteorological Services:	
- networks of stations	1,500
- training: Class I	500
Classes II and III (provided under Regional Training School)	-
Class IV	100
- headquarters buildings and facilities	1,100
- expert advice during development	500
Sudano-Sahelian Meteorological Centre and Regional Training School:	
- buildings and facilities	1,400
- expert international staff first 5 years	1,800
	6,700

Description

Networks of stations

Synoptic meteorology has been developed since the second World War mainly for the protection of aviation. Some sparse networks of rainfall and climatological stations are directly under the control of Directors of Meteorological Services. Special projects executed by UN and other agencies provide data from scattered sites, mainly near the large river basins in the Sudanian zone.

In the six Sudano-Sahelian countries networks of three APT, seven upper air and 74 synoptic stations have been established for WWW and there are plans for improvement of these networks for the Global Atmospheric Research Programme Atlantic Tropical Experiment (GATE). But there are considerable gaps in the networks particularly in the northern Sahelian zone. For development of networks towards the target basic network of WMO Regional Association I (Africa) and to provide adequate data for all purposes, it is necessary to establish additional stations as recommended in the table below.

Agro-meteorological, hydro-meteorological and climatological stations are too few in number and are concentrated in the main river basins where special projects have been established at particular stations. If there is to be an understanding of the fundamental and practical problems of water resources and agriculture it is essential to establish planned networks of stations and to centralize collection of observations covering the zone as a whole. Provision must also be made for future special projects which are expected to be developed for water resources and agriculture and particularly for such projects in the northern pastoral zone.

Existing rainfall stations are insufficient in number and gaps in the networks are far too large for comprehensive study of the element which is of primary importance to socio-economic development in a semi-arid zone subject to extended drought.

Because of the local difficulties of obtaining observers and of maintaining instruments and providing communications, it is recommended that, wherever possible, stations should have multiple functions. Synoptic stations in the basic networks should fulfil the functions of agro-meteorological and climatological stations. Agro-meteorological stations should provide data on elements required for general meteorology. River flow and lake-level stations should in all cases make observations of rainfall and should also fulfil the functions of agro-meteorological and climatological stations wherever possible.

In many cases, especially in the south and in river basins, it will be possible to up-grade existing stations at relatively low cost in instruments, manpower and communications, but the establishment of many new ones is necessary. One country with an area over a million square kilometres now has 12 synoptic stations but has only one agro-meteorological station, four climatological stations, five river-flow observation stations and 13 rainfall stations. On the other hand, another country of less than 300,000 square kilometres has seven synoptic stations and over 200 rainfall stations. Even this latter density, averaging one rainfall station for each 1,500 square kilometres, cannot provide rainfall data adequate for agricultural and water-resources planning and management.

The following table gives recommendations for the number of stations required to provide data for all sectors of the economy and indicates possible additional requirements for stations for specific projects. This first assessment of the number of stations required has necessarily been approximate. It is recommended that a detailed survey of existing and necessary networks be made in each of the six countries. Such surveys would occupy one agro-meteorologist and one hydro-meteorologist, working together, over four months and should be regarded as a preparatory stage in the supply of expert advice in subsequent establishment of station networks and of headquarters of national Meteorological Services.

Analysis of approximate requirements* for basic networks of observing stations (up-grading or new)

Type of station	Haute-Volta	Mali	Mauri-tanie	Niger	Sénégal	Tchad	Cost US $ 1,000
APT	1		1	1			150
Radiosonde		1	1	1		2	600
Radiowind	1	1	1	1		2	
Synoptic		2	4			4	120
Agro-met.							
i) basic	10	20	10	10	10	20	250
ii) special projects	5	10	5	10	5	10	
Climatolog.							
i) basic	20	35	30	30	30	35	200
ii) special projects	5	5	5	5	5	5	
River flow & lake level							
i) basic	20	40	5	15	25	40	170
ii) Special projects	5	20	5	5	25	25	
Rainfall							
i) basic	60	250	200	200	50	200	70
ii) special projects	100	100	50	50	100	100	
						Total	1.560
						+ survey	25

* Requirements for new additional stations only are shown for APT, radiosonde, radiowind and synoptic stations. For all other types of stations the figures include both new stations and those which need up-grading to standards in the national network. In all cases figures are inclusive of those appearing against types of stations appearing higher in the table.

Stores supplies, instrument repairs and calibrations

Improvement and expansion of national networks of observing stations will make larger demands for the supplies and control of instruments and stores in the six countries. It would be economical and ensure standardization to provide for a major part of these functions, including an instrument workshop, in the Sudano-Sahelian Meteorological Centre.

Processing of climatological and hydrological data and their utilization

Commendable efforts have been made especially during the recent drought, by Directors of Meteorological Services and other agencies to collect and make use of data from diverse sources not all of which are usually collected or recorded in various existing publications.

Each national Meteorological and Hydrological Service needs to be provided with the staff and facilities for collection, verification, summarization and storage of all data made within its country.

National Services also need to supply summaries and interpretations of all data for rapid and general dissemination at the national level as well as to provide specialist advice on all meteorological and hydrological matters.

A Sudano-Sahelian Meteorological Centre is required to prepare data for computer processing and to publish permanent records, to interpret data on the regional scale by map compilation, research and investigation and to make longer-period forecasts.

Training

Attention must also be focussed on the necessity of increased numbers of national personnel for Meteorological and Hydrological Services of the Sudano-Sahelian countries. Existing numbers are small and, with few exceptions, the national meteorologists have a background of training and experience only in meteorology for aeronautical purposes. Moreover at the higher levels there is a large proportion of expatriates and of older men for whom replacements must be anticipated.

It is proposed that provision should now be made for training of African meteorologists and hydrologists at all levels. The full benefit of this training cannot be reaped for some years - in the late 1970's in the case of technical officers and about 1980 for higher professionals. Delays in starting projects for training can only result in retarded application of meteorology and hydrology to development of the countries.

Class I Meteorologists and Hydrologists

There are extremely few fully qualified professional meteorologists and hydrologists among the nationals of the Sudano-Sahelian countries. Whilst only about half of the six countries have any Class I professionals, each country needs a minimum of four in its national

Meteorological Service with specialization in climatology and in synoptic, agro- and hydro-meteorology. Some countries have fellows under long-term training overseas but the total is only half a dozen and the distribution between the six countries is unequal.

The Sudano-Sahelian Meteorological Centre would require 11 Class I professionals for sub-regional investigations and longer-period forecasts and the training of technicians.

It is proposed that 35 national holders of the "Baccalauréat" should be awarded long-term fellowships of 5 years each to obtain a degree in meteorology and to carry out post-graduate studies in general meteorology, agro-meteorology or hydro-meteorology.

The ultimate solution for education and training of Class I personnel would be the establishment of a Department or a Chair of Meteorology in a university of one of the Sudano-Sahelian countries. Alternatively Class I training facilities for West African students could be established in another French-speaking country in Africa. However, since the facilities in various fields of meteorological applications is a complex task and requires careful study, it is proposed that as an interim measure the long-term fellowships should be tenable abroad.

Class II and III Personnel

There are also very few Class II African meteorologists in the Sudano-Sahelian countries. Whilst the number of Class III officers working in the national Meteorological Service and the Regional Meteorological Centre at Dakar amounts to about 30, there is only about the same number in all the other five countries put together. Hydrologists are very few in number.

Such numbers will be inadequate for provision of meteorological services to all sectors of the economy. It is proposed that in conjunction with the Sudano-Sahelian Meteorological Centre there should be established a Regional Training School providing education and practical training for Classes II and III meteorologists.

During the first five years of operation the School should have an output of:

Class II 2 courses each of 12 students and of 24-30 months

Class III 4 courses each of 12 students and of 12-15 months

Class IV personnel

Although larger numbers of Class IV personnel are already available for synoptic meteorology there will be necessity for considerable additions not only to man the climatological, agro-meteorological and hydrological stations but also to provide for retirments. It would be difficult to envisage the training of these junior officers in one centre. It is proposed that a training expert should spend a period of about 6 months in each country to conduct local training of a total of about 120 Class IV personnel. This approach has already been carried out by WMO in other regions of the world with considerable success.

Establishment of Headquarters of National Meteorological Services

At present the headquarters of National Meteorological Services are, with few exceptions, accommodated with and very closely associated with aviation services.

Not only will the Meteorological Services require larger accommodation than is at present available but also the association of their activities with the Ministries of Rural Economy, Agriculture and Water Resources needs emphasis. The existing National Hydrological Services are already very closely associated with these Ministries and are accommodated in buildings attached to them.

It is proposed that new headquarters of National Meteorological Services should be dissociated from buildings used entirely for aeronautical services, where this is feasible and has not already been done, and that financial provision be made for new buildings, office equipment, libraries and vehicles for station inspections.

Expert advice in establishment of National Meteorological Services

The organization and development of National Meteorological and Hydrological Services require the laying of sound foundations in the early stages under guidance of fully qualified and experienced international experts.

In the description of the establishment of networks of stations it was proposed that one agro-meteorologist and one hydro-meteorologist should carry out a detailed survey of requirements in networks of stations and that this survey should be regarded as a preparatory phase in the supply of expert advice in subsequent establishment of the networks and of headquarters services of National Meteorological Services. To these experts should be added, at the implementation stage, two other experts - one in climatology and one in instruments. A further expert in synoptic meteorology might become necessary.

These four or five experts, working as a team, would be required over a period of about four years to give advice and assistance as progress and problems developed in establishment of national services. The experts would move into each of the six countries of the Sudano-Sahelian zone as circumstances demanded.

Establishment of Sudano-Sahelian Meteorological Centre and Regional Training School

A description of the necessity for a Regional Training School has been given under the section dealing with training of Classes II and III personnel. In the interests of economy, it is proposed that the School should share accommodation and professional staff with the Sudano-Sahelian Meteorological Centre.

Many of the meteorological problems of the Sudano-Sahelian zone are common to all six countries which have joined together in the Permanent Inter-State Committee for the Fight against Drought in the Sahel and which together have a total population of about twenty-five million people. Although each of the six countries needs the maintenance of networks of observing stations and provision of

service at the national level, there are some services, in addition to training, which can be appropriately provided to all countries from a sub-regional centre.

The Centre Inter-Africain d'Etudes Hydrauliques in Ouagadougou provides centralized services and co-ordination in hydrological services. The Regional Meteorological Centre and the Headquarters of ASECNA in Dakar provide centralized services and co-ordination in aeronautical and regional scale synoptic meteorology.

It is not proposed that this Centre should take over at an early stage some of the meteorological functions now being performed by other agencies because of gaps in meteorological organization. It may, however, become desirable for the Centre to be developed eventually into an organization responsible at the regional level for all general applications of meteorology and, in co-operation with other regional agencies, for meteorological activity in inter-disciplinary fields.

It is recommended that the Centre and School should be staffed by 11 experts, initally expatriate staff:

1 Director
1 Deputy Director
2 Synoptic Meteorologists
2 Climatologists
2 Agro-meteorologists
2 Hydro-meteorologists
1 Instrument technician

About one third of the working time of this staff should be devoted to training of Classes II and III students in the School.

Nationals of the six countries would be expected to replace expatriates as soon as adequate numbers of trained and experienced Class I African meteorologists became available.

Previous proposals for development of National Meteorological Services

In this appendix the development of National Meteorological Services in the Sudano-Sahelian countries has been dealt with as a whole since many of the problems arising in these countries are common to all of them. However, it is necessary to point out that, for some individual countries and some aspects of the general problems, separate proposals have been made elsewhere and some action has already been taken.

A UNDP project for the creation of a National Meteorological Service in Senegal (duration 4 years, $900,000) was started in April 1973. A UNDP project for development of agro-meteorological services in Mauritania (duration 1 year, $ 30,000) has been drawn up and submitted for approval. Some countries already have a few students in general meteorology, agro-meteorology and hydro-meteorology under training overseas. Such proposals and action should be taken as falling within and requiring co-ordination with the projects recommended in this document.